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Modeling Quality Assessment of the Supply Chains

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The article presents how to use methods and tools in the area of quality engineering to assess the supply chain, having the example of the food industry. It outlines the regulatory requirements and standardization documents for the transport of dairy products. Using a questionnaire conducted it selects criteria that were directly used to assess the quality of the supply chain (network). Then, using the Pareto-Lorenz diagram the most important criteria were selected, which were also used in the study.

Keywords: quality, quality assessment, supply network.

1. INTRODUCTION

Globalization and competition, as well as a steady growth of customer requirements forces ensuring high level of quality of all the processes occurring on the market. This also applies to the supply network of the companies. To meet the expectations, the companies are forced to look for innovative, pioneering solutions that ensure the achievement of the intended objective. One of these solutions can be certification and quality assessment. The problem occurs at the very beginning of the discussion, namely, how to understand the quality, what high and low quality means, what are the consequences of the lack of quality, how to interpret the quality of the supply chains? Following this line of reasoning - how to assess the quality of the supply chains? The difficulty facing the businesses, relies largely on the complexity of the problem which is a subject to evaluation, on a large number of conditions and criteria which cause the problem to be sometimes complex, multidimensional and often of multi-criteria.

The aim of the article is the choice of the most important evaluation criteria and propose a method to assess the quality of the supply network using the example of the food industry. The study used the Pareto-Lorenz histogram and mathematical modelling.

2. ANALYSIS OF THE SUPPLY CHAINS' QUALITY ASSESSMENT

Having the defined criteria for assessing the quality of the supply network, it is possible to use a variety of methods and tools to make this assessment. The elements of the supply chains of the food business are: the company, the transport company and the supplier. The population of these elements represented by vectors create an evaluation model. The adopted order of the components in the form of vector is arbitrary and it does not matter substantively.

In order to reflect the structural relationships between the elements, the model can be represented as a diagram.

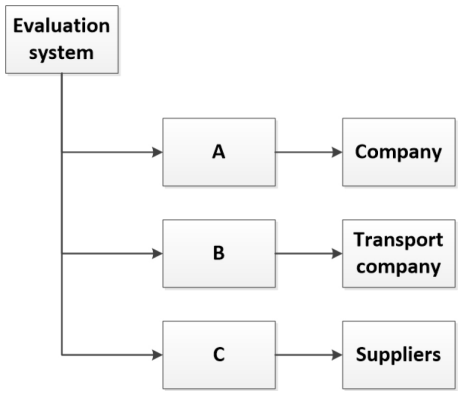

Fig. 1. Graphic presentation of the evaluation system model.

Source: A. Jóźwiak, A. Świderski, J. Zelkowski, A*spekty modelowania oceny jakości sieci dostaw branży spożywczej*, Scientific Works of the Warsaw University of Technology,Warszawa, 2016.

To determine the effect of each item on the final assessment of the supply network it is necessary to create a so called score profile in which all the components have one scale. To do this, a list of characteristics was made up (elements of the supply network), next to which there is the graphical presentation of the scale. Then the evaluation was indicated (level of significance) v_i for each of them. The points obtained were joined with the line. The following evaluation scale was adopted (Fig. 2):

2-permitting
3-satisfactory
4-good
5-very good

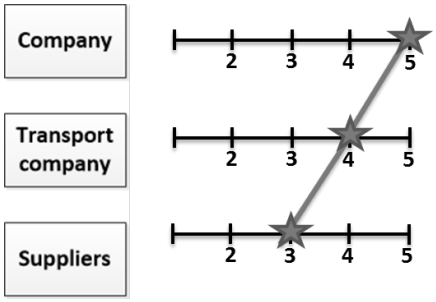

Fig. 2. The quality assessment profile of the supply chains based on the ratings of its components. Source: Own compilation.

Each component was assessed independently, thus the profile of the assessment is of purely cognitive character, although it is a starting point for further analysis.

The next step is to calculate a weighted sum of grades. This process helps to determine the magnitude of the influence of the individual components. In a situation where the improvement of the assessment occurs for one component and affects the other components, it will be necessary to introduce the coefficients reflecting the perceived changes. These are the structural weights w_i [7]. The procedure for determining the number w_i is as follows: first a comparison of any two components is made, then the comparison results are summarized in the table. For each component it is being counted, how many times it has been identified as having a higher share, thereby determining the number representative for the incidence of the advantage. Indication of the advantages of individual members of the network are shown in Table 1. The final step is to create an equation with unknown x and having solved it, calculation of the structural weights for each component by multiplying the value of x by the advantage incidence of the given component.

Table 1. The advantage incidence indications of individual network participants.

	A	B	C	Frequency advantage
A	A	A	A	**3**
B		B	B	**2**
C			C	**1**

Source: Own compilation

Assuming that the partial shares add up to the total share equal to 1, it is possible to make an equation:

$$3x + 2x + x = 1 \qquad (1)$$
$$x = 0{,}166\ldots$$

- Therefore, the shares of individual elements are, according to the formula:

$$w_i = x * frequency\ of\ prevalence \qquad (2)$$

- for the company - w_a= 0,166·3=0,50, which can be interpreted as a share of 50%,
- for the transport company - w_b=0,166·2=0,33, which can be interpreted as a share of 33%,
- for the supplier- w_c=0,166·1=0,17, which can be interpreted as a share of 17%.

The largest effect on the supply network quality evaluation has the company, with the transport company coming second, and the smallest share of the supplier.

Knowing the structural weights w_i and the predetermined activity level assessments v_i it is possible to calculate the share of each component in the supply network quality evaluation [6]:

$$a_i = w_i \cdot v_i \qquad (3)$$

So that the global assessment will be equal to:

$$a_0 = \sum_{i=1}^{k} a_i = \sum_{i=1}^{k} w_i \cdot v_i \qquad (4)$$

For the example shown in the article, the global assessment is:

$$a_0 = 0{,}50 \cdot 5 + 0{,}33 \cdot 4 + 0{,}17 \cdot 3 = 4{,}32$$

This can be interpreted as a rating higher than good, but less than very good. The evaluation rating is lowered by the suppliers and transport companies. These are the elements that need to be improved or their impact on the quality of the supply chain functioning needs to be increased.

3. CRITERIA FOR THE ASSESSMENT OF THE SUPPLY CHAINS QUALITY

Improving quality is a continuous activity. For this reason, one should regularly review the processes or the manufactured products in order to maintain their quality at the right level [9].

In order to assess the quality of the supply network of the food business company, a survey was conducted regarding the definition of the most important criteria by individual members of the supply network, which included: the company, transport company and suppliers. The survey used the assessment scale from 1 to 10 (where 1- of little importance, 10 - very important) in the context of the impact of the given criterion on the assessment of the supply network quality. Their significance was determined for the individual assessment criteria. They are presented in Tables 2-4.

Table 2. The significance of the criteria defined by the company.

No.	Criteria of the company	Significance of the criterion
1	maintaining the conditions of transport	2
2	accuracy of the measurement	8
3	punctuality of the deliveries	3
4	completeness of the supplies	9
5	operation	4
6	size of the loading space	4
7	predictability	2
8	costs	9
9	time	9
10	other	1

Source: Own compilation.

Table 3. The significance of the criteria defined by the transport company.

No.	Criteria of the transport company	Significance of the criterion
1	punctuality of the collections	5
2	completeness of the supplies	5
3	maintaining the conditions of transport	4
4	costs	10
5	number of car breakdowns	4
6	time	10
7	effectiveness	8
8	minimum stoppage of the vehicle without orders	4
9	accuracy of the measurement	10
10	cleanability	1
11	ergonomics of the vehicle	2
12	repairability	3
13	other	1

Source: Own compilation.

Table 4. The significance of the criteria defined by the suppliers.

No.	Criteria of the supplier	Significance of the criterion
1	accuracy of the measurement	10
2	reloading time	3
3	size of the loading space	2
4	punctuality of the collections	8
5	safety of the sample	9
6	flexibility of the collections	2
7	other	1

Source: Own compilation.

A tool that makes reading data and its interpretation easier is the histogram. It shows the following general tendency measures [2]:

- average - the sum of all data measured or counted divided by the total number of data units;
- modal - the most common value in a data set, or in the case of the histogram, the largest interval that includes the same values;
- median – medium value of all data units.

Figures 1-3 show the significance criteria histograms defined by the various participants in the supply network.

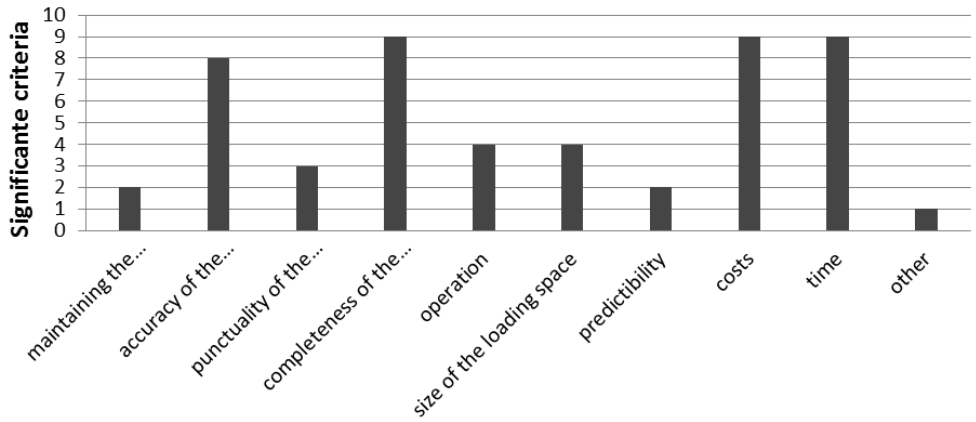

Fig. 1. Criteria significance defined by the company.
Source: Own compilation.

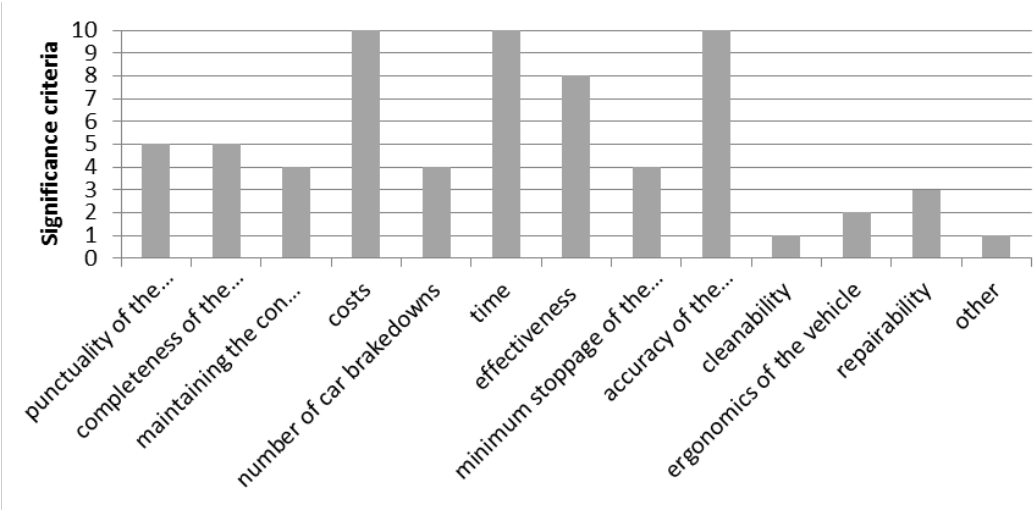

Fig. 2. Criteria significance defined by the transport company.
Source: Own compilation.

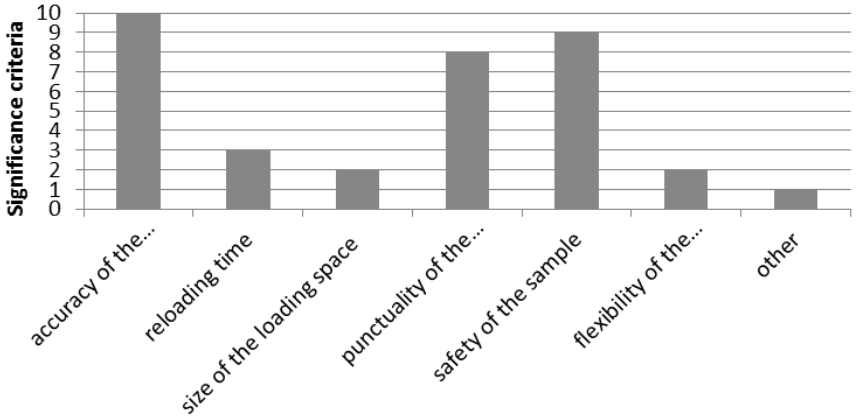

Fig. 3. Criteria significance defined by the suppliers.
Source: Own compilation.

4. QUALITY EVALUATION OF THE SUPPLY CHAINS COMPONENTS

Using criteria and their level of significance defined by the participants of the supply network, it is possible to calculate the share of each component (each criterion) of individual network elements in the evaluation of the supply network quality, based on which one can obtain the global evaluation of the supply chain participants.

For the formal reasons in all cases to be analysed, the criterion – 'other' was rejected. However, the scale of evaluation is appropriate to the scale of the criterion significance proposed in the survey (scale ranging from 1 to 10).

The equation will take the form:

$$6x + 6x + 9x + 9x + 5x + 6x + 5x + 4x + 4x + x + 2x + x = 1 \quad (6)$$
$$x = 0{,}017$$

Table 5. Indications of the incidences of the advantages of criteria for the company quality assessment.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Incidence of the advantages**
1. maintaining the conditions of transport	1	2	1	4	1	1	1	1	1	**7**
2. accuracy of the measurement		2	2	2	2	2	2	2	2	**8**
3. punctuality of the deliveries			3	4	3	3	3	8	9	**4**
4. completeness of the supplies				4	4	4	4	4	4	**6**
5. operation					5	5	7	8	9	**2**
6. size of the loading space						6	6	8	9	**2**
7. predictability							7	8	9	**1**
8. costs								8	8	**2**
9. time									9	**1**

Source: Own compilation.

The equation will take the form:

$$\ldots\ 7x + 8x + 4x + 6x + 2x + 2x + x + 2x + x = 1 \quad (5)$$
$$x = 0{,}03$$

Therefore, the shares of individual elements are: W_{1a}=0,21; W_{2a}=0,24; W_{3a}=0,12; W_{4a}=0,16; W_{5a}=0,06; W_{6a}=0,06; W_{7a}=0,03; W_{8a}=0,06; W_{9a}=0,03.

Global assessment of the company criteria for evaluating the supply chain quality has a value:

$$a_a = 0{,}21 \cdot 2 + 0{,}24 \cdot 8 + 0{,}12 \cdot 3 + 0{,}16 \cdot 9 + 0{,}06 \cdot 4 + 0{,}06 \cdot 4 + 0{,}03 \cdot 2 + 0{,}06 \cdot 9 + 0{,}03 \cdot 9 = 5{,}49$$

Therefore, the shares of individual elements are: W_{1b}=0,102; W_{2b}=0,102; W_{3b}=0,153; W_{4b}=0,153; W_{5b}=0,085; W_{6b}=0,102; W_{7b}=0,085; W_{8b}=0,068; W_{9b}=0,068; W_{10b}=0,017; W_{11b}=0,034; W_{12b}=0,017.

Global assessment of the transport company criteria for evaluating the supply chain quality has a value:

$$a_b = 0{,}102 \cdot 5 + 0{,}102 \cdot 5 + 0{,}153 \cdot 4 + 0{,}153 \cdot 10 + 0{,}085 \cdot 4 + 0{,}102 \cdot 10 + 0{,}085 \cdot 8 + 0{,}068 \cdot 4 + 0{,}068 \cdot 10 + 0{,}017 \cdot 1 + 0{,}034 \cdot 2 + 0{,}017 \cdot 3 = 6{,}29$$

Table 6. Indications of the incidences of the advantages of criteria for the transport company quality assessment.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Incidence of the advantages**
1. punctuality of the collections	1	2	3	4	5	1	7	1	9	1	1	1	**6**
2. completeness of the supplies		2	2	4	2	2	7	8	9	2	2	2	**6**
3. maintaining the conditions of transport			3	4	3	3	3	3	3	3	3	3	**9**
4. costs				4	4	4	4	4	4	4	4	4	**9**
5. number of car breakdowns					5	6	7	5	9	5	5	5	**5**
6. time						6	6	6	9	6	6	6	**6**
7. effectiveness							7	7	9	7	7	7	**5**
8. minimum stoppage of the vehicle without orders								8	9	8	8	8	**4**
9. accuracy of the measurement									9	9	9	9	**4**
10. cleanability										10	11	12	**1**
11. ergonomics of the vehicle											11	11	**2**
12. repairability												12	**1**

Source: Own compilation.

Table 7. Indications of the incidences of the advantages of criteria for the suppliers quality assessment.

	1	2	3	4	5	6	Incidence of the advantages
1. accuracy of the measurement	1	1	1	1	5	1	**5**
2. reloading time		2	2	4	4	4	**2**
3. size of the loading space			3	4	5	3	**2**
4. punctuality of the collections				4	5	4	**2**
5. safety of the sample					5	5	**2**
6. flexibility of the collections						6	**1**

Source: Own compilation.

This method using more numerous criteria becomes complicated and time consuming. One of the tools that simplifies this type of calculation is Pareto-Lorenz diagram, which leads to identifying the factors having the greatest impact on the selected values, describing the process result or product characteristics. It illustrates the uneven distribution „result-factor", indicating that a relatively small number of factors determine a significant share of results [4].

The use of the Pareto-Lorenz diagram allowed to identify the most important evaluation criteria.

The diagram shows that the 4 criteria (time, cost, supply completeness and accuracy of measurement) are most important and together constitute approx. 70% of the total weight of the criteria of the company. Other criteria are less important and are approx. 30%. Therefore, they will not be taken into account in the subsequent deliberations. Similarly, a review of the criteria of the transport company and suppliers has been conducted (Fig. 5 and 6).

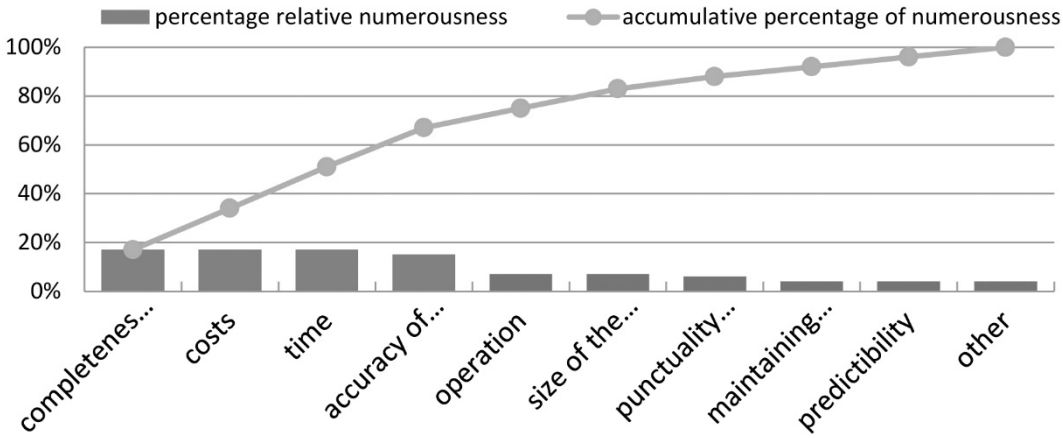

Fig. 4. The Pareto-Lorenz diagram of the defined enterprise's criteria weights
Source: Own compilation

The equation will take the form:

$$5x + 2x + 2x + 2x + 2x + x = 1 \qquad (7)$$
$$x = 0{,}07$$

Therefore, the shares of individual elements are: W_{1c}=0,35; W_{2c}=0,14; W_{3c}=0,14; W_{4c}=0,14; W_{5c}=0,14; W_{6c}=0,07.

Global assessment of the suppliers criteria for evaluating the supply chain quality has a value:

$$a_c = 0{,}35 \cdot 10 + 0{,}14 \cdot 3 + 0{,}14 \cdot 2 + 0{,}14 \cdot 8 + 0{,}14 \cdot 9 + 0{,}07 \cdot 2 = 6{,}72$$

In summary, the global assessment of the criteria for individual supply network elements are as follows: a_a=5,49; a_b=6,29; a_c=6,72.

It can be concluded that the best element of the supply chain are the suppliers, while the weakest the company. It is worth noting that the company is the main "organizer" of the supply chain and the requirements in respect to this element are the largest, which resulted in the ratings.

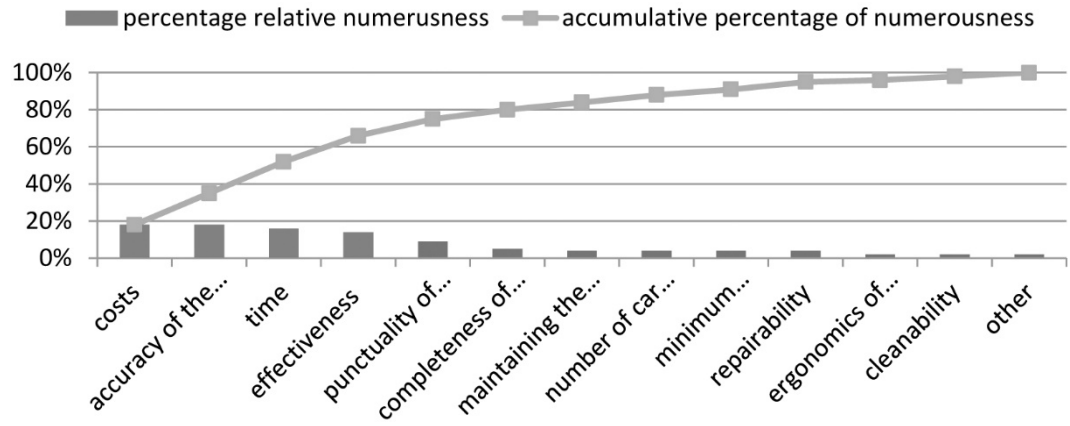

Fig. 5. The Pareto-Lorenz diagram of the defined transport company's criteria weights
Source: Own compilation.

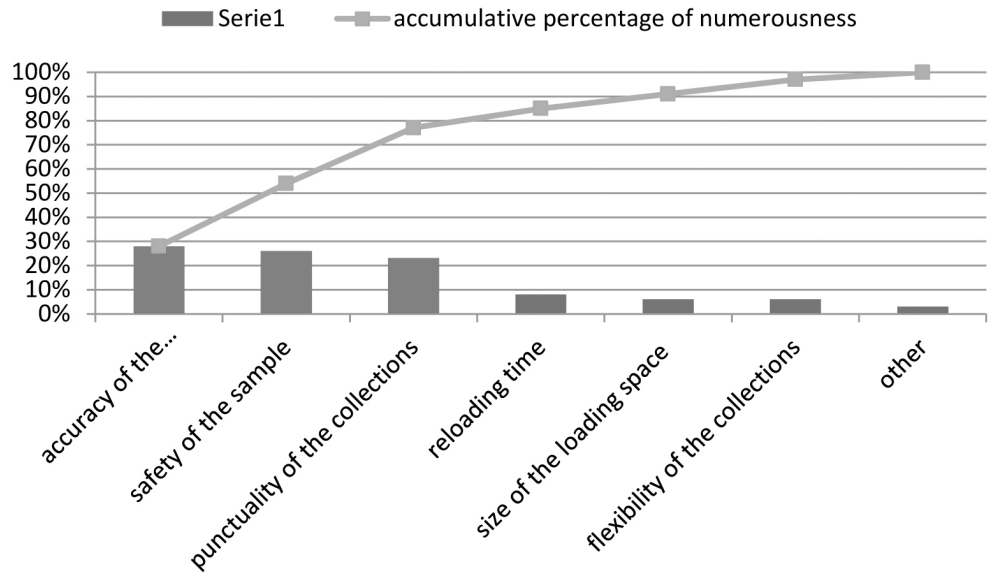

Fig. 6. The Pareto-Lorenz diagram of the defined suppliers' criteria weights.
Source: Own compilation.

The use of this tool will simplify the calculation algorithm of the method shown, as illustrated in Tables 8-10.

Table 8. Indications of the incidences of the advantages of criteria for the company quality assessment.

	1	2	3	4	Incidence of the advantages
1. time	1	1	1	1	**4**
2. costs		2	2	2	**3**
3. completeness of the supplies			3	4	**1**
4. accuracy of the measurement				4	**1**

Source: Own compilation.

The equation will take the form:

$$4xp + 3xp + xp + xp = 1 \qquad (8)$$
$$xp = 0{,}1$$

Therefore, the shares of individual elements are: Wp_{1a}=0,4; Wp_{2a}=0,3; Wp_{3a}=0,1; Wp_{4a}=0,1.

Global assessment of the company criteria for evaluating the supply chain quality has a value:

$$a_{ap} = 0{,}4 \cdot 9 + 0{,}3 \cdot 9 + 0{,}1 \cdot 9 + 0{,}1 \cdot 8 = 8$$

Table 9. Indications of the incidences of the advantages of criteria for the transport company quality assessment.

	1	2	3	4	Incidence of the advantages
1. time	1	2	1	1	**3**
2. costs		2	2	2	**3**
3. effectiveness			3	3	**2**
4. accuracy of the measurement				4	**1**

Source: Own compilation.

The equation will take the form:

$$3xp + 3xp + 2xp + xp = 1 \quad (9)$$
$$xp = 0{,}1$$

Therefore, the shares of individual elements are: Wp_{1b}=0,3; Wp_{2b}=0,3; Wp_{3b}=0,2; Wp_{4b}=0,1.

Global assessment of the transport company criteria for evaluating the supply chain quality has a value:

$$a_{bp} = 0{,}3 \cdot 10 + 0{,}3 \cdot 10 + 0{,}2 \cdot 8 + 0{,}1 \cdot 10 = 8{,}6$$

Table 10. Indications of the incidences of the advantages of criteria for the suppliers quality assessment.

	1	2	3	Incidence of the advantages
1. punctuality of the collections	1	2	3	**1**
2. accuracy of the measurement		2	2	**2**
3. safety of the sample			3	**1**

Source: Own compilation.

The equation will take the form:

$$xp + 2xp + xp = 1 \quad (10)$$
$$xp = 0{,}25$$

Therefore, the shares of individual elements are: Wp_{1C}=0,25; Wp_{2C}=0,50; Wp_{3C}=0,025.

Global assessment of the suppliers criteria for evaluating the supply chain quality has a value:

$$a_{cp} = 0{,}25 \cdot 8 + 0{,}5 \cdot 10 + 0{,}25 \cdot 9 = 9{,}25$$

In summary, the global assessments of the criteria selected by the use of Pareto-Lorenz diagram of the individual network elements are as follows: a_{ap}=8; a_{bp}=8,6; a_{cp}=9,25.

Summary of global assessments of the supply chain elements using, for the purpose of the analysis, all the criteria and the criteria selected by the use of the Pareto-Lorenz diagram are presented in Table 11.

Table 11. Summary of global assessments of the supply chain elements.

	Global assessments obtained using ALL criteria	Global assessments obtained using SELECTED criteria
Company	**5,49**	**8**
Transport firm	**6,29**	**8,6**
Suppliers	**6,72**	**9,25**

Source: Own compilation.

The application of Pareto-Lorenz diagram significantly simplified and shortened the calculation algorithm of the presented method. At the same time it confirmed the results, where the highest rating was given to the suppliers, while the lowest to the company.

5. CONCLUSION

The problem of evaluating the quality of supply chains is complex and multifaceted. It requires taking into account different priorities relevant to all elements of the supply chain. Such an approach requires comprehensive analysis and systematic description of the relationships between the network elements. The tools and methods used and discussed in the article support defining and selecting relevant criteria for evaluating the quality of the supply network and present their impact on the global assessment.

The topic, undertaken in the article, requires further research on improving methods for assessing and modelling the quality of the supply network.

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